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A Feasibility Study of A Zero Energy Building in Egypt

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Abstract— *According to studies, buildings use around 40% of the total energy consumption in the world. Most of this consumed energy comes from fossil fuel, one of the sources of environmental pollution. The Net Zero Energy Building (NZEB) is an alternative to this alarming pollution. With its reduced energy needs and renewable energy systems, a ZEB can return as much energy as it takes from the utility on an annual basis. Thus the main objective of this study is to discuss the economical and friendly environmental renewable energy system integrated to building in Egypt to be (NZEB) economical by maximizing the renewable energy fraction and minimizing the greenhouse gases (GHG) emissions. The system consists of two renewable energy sources, comprising photovoltaic system, a wind turbine are considered for the proposed building under the study. By Utilizing the well-known Hybrid Optimization of Multiple Electric Renewables software to get the optimal configuration of a hybrid renewable energy system, based on the user inputs of loads, costs, technical details, solar and wind resources availability.*

Index Terms—Net Zero Energy Building (NZEB); Renewable Energy Resources (RES); Greenhouse gases (GHG) emissions; cost of energy (COE); net present cost (NPC); Hybrid Optimization of Multiple Electric Renewables (Homer)

1. Introduction

The building sector alone including all building types- contributes with 40% of total energy consumption and one third of greenhouse gas emissions globally, and the numbers are even higher in Egypt, reaching 51% of total energy sold in 2014 and the harmful emissions in Egypt, the CO2 per capita reached 3.88 ton/year in the latest statistics provided by CAPMAS for the year 2011 rising from 2.93 ton/year in 2008 [1]. This is due to the fact that 75% of total global energy demand is supplied by the burning of fossil fuels .Putting in mind the problems associated with generating energy from these resources .It is worth mentioning as well that Egypt has significant renewable energy potential that is yet to be realized [2].

A recent study has revealed that improving energy efficiency in buildings is the least costly way to reduce a large quantity of air pollution. In order to achieve breakthrough solutions to this problem, it's necessary to integrate RES to design the buildings of the future mainly called Net Zero Energy Building (NZEB). There are several definitions for a ZEB. Each definition differs depending on the boundary and metric used to define the building. The definition of a net zero energy building (NZEB) according to the U.S. Department of Energy (DOE) Building Technologies Program is: "A net zero energy building is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies [3].

There are two approaches can be considered for buildings:

1- A grid-tied net-zero Buildings normally uses conventional energy sources from utility companies when on-site energy production is not enough to meet building loads. When the on-site generation is greater than the building's loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use [4]. It is almost impossible to offset building energy demand without being tied to grid with the current technologies.
2- Zero Stand Alone Buildings are buildings that do not require connection to the grid or only as a backup. Standalone buildings can autonomously supply themselves with energy, as they have the capacity to store energy for night-time or winter time use [5].

The existing buildings represent both the problem and the solution, because if a clear methodology is proposed to convert existing buildings into zero-energy buildings then the majority of the urban fabric will be affected. Unlike solutions for new design buildings that would take a lot of time to show results, working on existing buildings would reflect immediately on the current energy consumption situation.

Three categories are required to retrofitting building:

1- Demand side management technologies, is two major parts: heating and cooling demand reduction, and energy efficient equipment and low energy technologies.
2- Supply side management technologies is the different renewable energy systems.
3- Energy consumption patterns, was denoted as human factors because the consumption level is basically determined by the users' behavior for ZEB design.

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Optimal design strategies and energy systems, including passive design parameters (external walls, window to wall ratios and orientations) and energy efficient mechanical systems as well as renewable energy systems, were provided by employing EnergyPlus and TRNSYS 16 simulation software [8].

2. NET ZERO ENERGY BUILDINGS IN EGYPT

In Egypt, 74% of the electricity used is consumed towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones. So if the building insulation efficiency was enhanced, the energy saving will be significant, the nZEB solution seems be fit perfectly where nZEB considered the renewable energy goal and load reduction. However, then no literature provides any data about existing nZEBs in Egypt, and only a small number of research about that subject.
In [6] The study provides two building scenarios of nZEBs in Borg El Arab city: Low investment scenario (LIS) and High investment scenario (HIS) and both were compared to a benchmark scenario that represents the minimum requirements of the Egyptian Energy codes, The study proves that energy efficient buildings could be built in the Egyptian climate and context if the building envelope and the overall insulation were designed to decrease the building's energy.
In [7] The study provides two building scenarios of nZEBs in Borg El Arab city to proves that energy efficient buildings could be built in the Egyptian climate and context if the building envelope and the overall insulation were designed to decrease the building's energy.

Egypt have good potential for using solar and wind resources , the most adequate renewable energy systems that can be used in a ZEB: solar panels (thermal and electric), small wind turbine , specially PV and solar thermal systems play a central role in nZEBs in general . The use of renewable energy offers environmental benefits in the form of reduced CO2 pollution, combining several renewable energy sources to form hybrid systems, whether off-grid or grid connected systems could provide more benefits by reducing CO2 emissions further and providing a reliable supply of electricity in all load conditions [9]; [10].
Few researchers have focused on a techno-economic feasibility evaluation of hybrid renewable power system in Egypt. Additionally, few works have been published to solve the problem Egypt is facing, the shortage of electrical power.
The following is a highlight about these attempts:
[12] discussed renewable energy systems for the new cites in Egypt by evaluating PV systems, with different renewable energy systems, to choose the most economical system; taking into consideration the environmental impact. The optimum combination was PV and diesel with net present cost (NPC) of $107,255 and COE of $0.271/kWh.
[13]; [14] is discuss how to select the optimum city from five touristic Egyptian cities (Luxor, Giza, Alexandria, Qena and Aswan) to establish a zero energy tourist village. It was found that Alexandria is the optimum city for a PV/wind/diesel/battery system according to the amount of GHG emitted compared to the other cities if the effects of ambient temperature are considered and GHG emission penalties are applied. Then discussed the economical and the environmental analysis of a net zero energy (NZE) tourist village in Alexandria, Egypt.

This work discusses two main objectives as follows:
1. Choose the optimal integrated renewable energy system (IRES) for an actual existing residential buildings in Egypt. This chosen is according to minimize the net present cost and emission. Two systems are used in this work. This systems are stand-alone system and grid connected system [11]. Cost analysis is studied in these systems without any retrofitting technology. Some retrofitting action must be attempt to study the changes in the energy & cost analysis.
2. The overall system cost will obtain to calculate the saving results from the system conversion (from conventional to zero energy system).

This paper is organized as follows:
Section III describe the renewable energy system component. Section V &IV is for Simulation of Renewable energy system and data collection. In the section VI simulation results are presented and discussed.
This research will utilize an actual residential building in Egypt as its case study. In [11] some changes to the envelope are proposed for the same building using market available products in order to enhance the energy performance of the building and decrease the amount of energy needed to the minimum, by using energy simulation program for building to test the feasibility of proposed methodology and determine the amount of energy saved by the retrofit actions. If the energy performance could be enhanced and the electricity could be generated through renewable system, then the building can be a zero-energy building.

3. RENEWABLE ENERGY SYSTEM COMPONENTS

The renewable energy system consists of the following components:
1. BWC Excel-R wind turbine.
2. Photovoltaic panel.
3. Trojan L16P Battery.

4. Converter.
5. Diesel generator.

1- Wind Turbine:

In this simulation, Bergey Wind Power's BWC Excel-R model is considered. It has a rated capacity of 7.5 kW. Its initial cost is $28500 and its replacement at 24500$. Annual operation and maintenance cost is 200$. Its life time is estimated at 25 years, a number from 1, 2 is considered.

2- Photovoltaic panel:

Photovoltaic panel is considered in the scheme, with initial and replacement cost 600$ with rated power 1k watt sizes to be considered are (2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 35 40 50).

3- Trojan L16P Battery:

Trojan L16P Battery models (6 V, 360Ah, 1.075 kWh), Cost of one battery is 275$ and maintenance cost 4$, a number of unit considered are (0 18 24 26 28 30 35 40 45 50 55 60 100).

4- Converter:

For a 1 kW converter the installation costs are taken as $750, number of units to be considered (1 4 6 8 10 14 15 16 17 18 19 20 22 26 30) KW.

5- Diesel generator:

For the diesel generator sizes of diesel generator to consider in simulation vary from 1 to 10 kW. The initial and replacement cost for 5kw are respectively (3750, 3000$) their operation and maintenance are of 0.05$/hr.

4. SIMULATIONS OF RENEWABLE ENERGY SYSTEM

To select an economical alternative of a standalone renewable energy system, a HOMER(hybrid optimization model for electric renewables) analysis is implemented to simulate the operation of the proposed system along the year by making an energy balance between the generation and the load to determine the feasible system architecture which meet the load demand under the site condition beside specifying the cost-effective combination based on the total net present cost [TNPC] which is the summation of all the costs and revenue all over the project life time which is assumed 25 years. [15].

5. DATA COLLECTION

1. Building data

The case study building is a 5 story residential building with two apartments per floor each of an approximate area of 140 m2 and total surface area of the building is 300 m2 ,The building is located in an average residential community in Egypt, Cairo ,Nasr City area with orientation North-South .

The annual peak load is 25 KW with energy consumption of 180.82 KWh/day and the daily profile of the load is shown in Fig. (1)

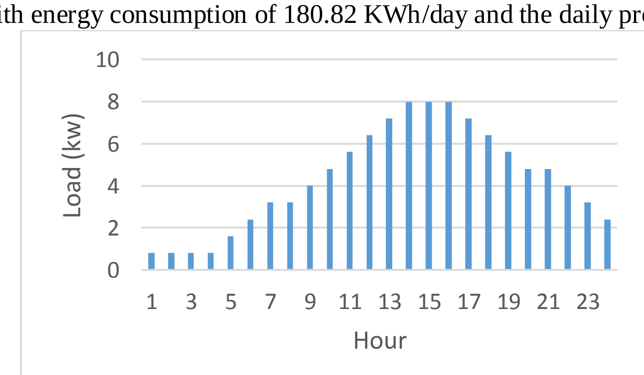

Fig.1: daily load profile

2. Wind And Solar Resources

The annual average wind speed and the annual average solar insolation level at Cairo is 4.76 m/s and 5.35 kWh/m2/day respectively, the monthly wind speed variation, the monthly clearness index and the daily radiation are shown in Fig. (2) and Fig. (3).

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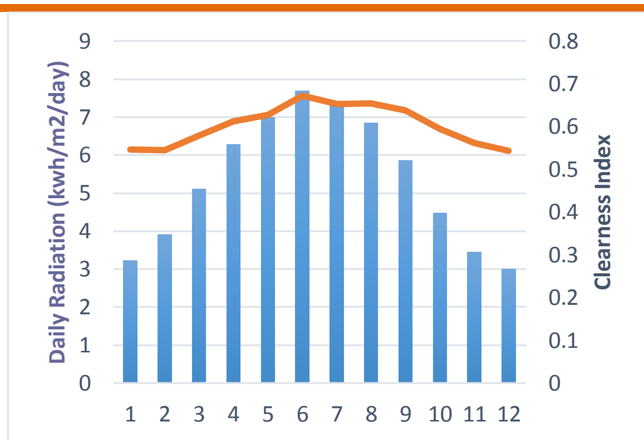

Fig. 2. The average monthly solar radiation data and the clearness index values.

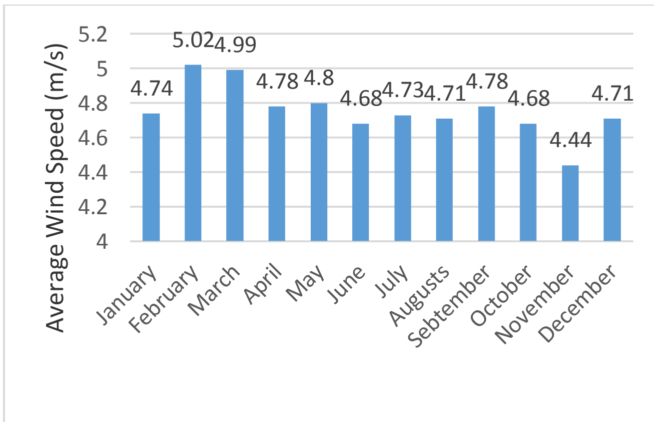

Fig. 3. The average monthly wind speed data.

6. Simulation Results

There are two cases of building to be considered as follows:
Case1: A. standalone building
B. grid –tied building
This case will be performed before any retrofitting actions.
Case2: A. standalone building
B. grid –tied building
And will be performed after retrofitting actions.

Case1

A. Standalone building

Fig.4 shows Design of Wind, PV and Diesel System

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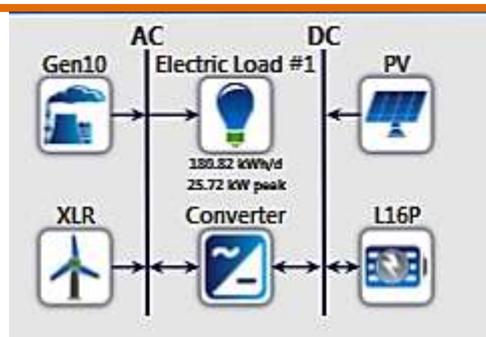

Fig.4: Wind, PV and Diesel System.

The simulation results present the optimum combination:
50kw PV 12KW generator, 80 battery and 17KW converter, with initial cost: 69,350$, operating cost: 8,885$/year, cost of energy: 0.223 $/KWh and net present cost 189, 99$.
Fig. (5) Shows the energy yield of the optimum solution.

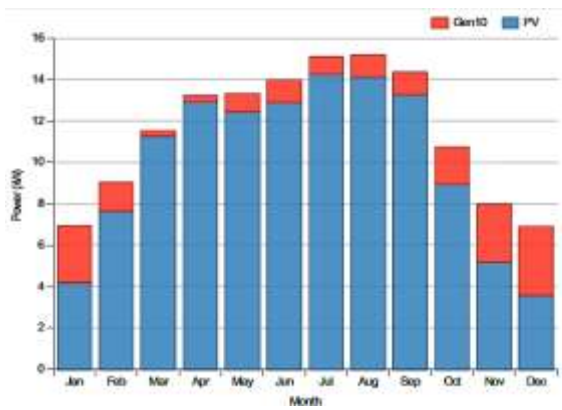

Fig.5: PV and Wind Electric Production

B. Grid-tied building

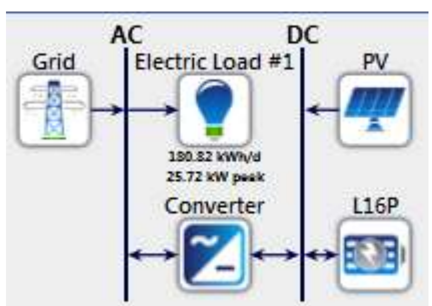

Fig.6: PV-Grid and Diesel System.

The simulation results present the optimum combination:
28kw PV, 20KW grid, 0 battery and 26KW converter, with initial cost: 23,300$, cost of energy: 0.0474 $/KWh and net present cost 47,521$.
Table. (I) shows the energy schedule of Grid.

TABLE I
Energy schedule of Grid.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)
January	2,723	1,110	1,613	14	$112.41
February	2,231	997	1,234	15	$83.79
March	2,663	1,194	1,468	18	$99.56
April	2,715	1,103	1,612	20	$112.42
May	2,944	951	1,993	20	$145.18
June	3,197	816	2,380	20	$178.19
July	3,318	730	2,587	20	$196.03
August	3,404	802	2,602	20	$196.11
September	3,228	1,041	2,188	20	$159.40
October	3,026	932	2,094	20	$153.51
November	2,816	989	1,826	19	$131.25
December	2,822	980	1,841	17	$132.58
Annual	35,084	11,645	23,439	20	$1,700.40

Case2

As the existing buildings in the Egyptian context have poor building envelope .This is translated in poor energy performance, where higher amounts of energy are needed to maintain thermal comfort and compensate for this leaking.
[11] discussed the retrofit technologies that compensate for the inefficiencies of the current building status in table.(II).

TABLE II
Cost analysis for envelope retrofit action

Item	Description	Overall price (LE)
Wall Insulation	Marmox 2 cm thick sheets	109,378
Roof Insulation	Tilefoam 2.5 cm thick tiles	26,265
Window system	Double glazed aluminum section	144,000
Insulation Film	P18 reflective film	26,156
Total price		**305,799**

After considering the envelope retrofit actions the average annual electricity consumption is decreased to (44000 kWh, 120.54 KWh/day and peak load is 17.14 KW) instead of (66000 kWh, 180.82 KWh/day and peak load is 25.6 KW) in the current existing case as per the simulation results.

A. Standalone building

The simulation results present the optimum combination for case2: 50kw PV, 6KW generator, 80 battery and 11KW converter, with initial cost: 60,350$, cost of energy 0.222 $/KWh and net present cost 126,21$ Fig. (7) Shows the energy yield of the optimum solution.

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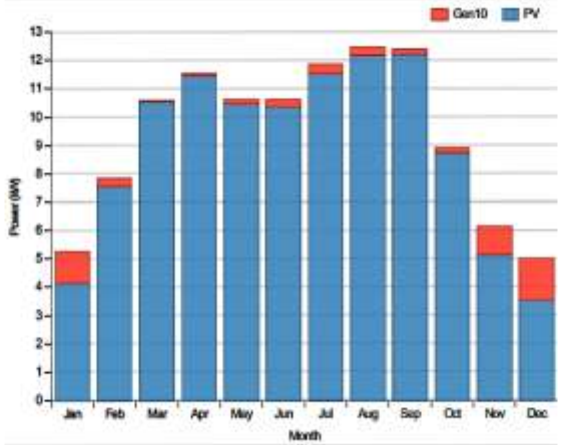

Fig.7: PV and Wind Electric Production

B. Grid-tied building

The simulation results present the optimum combination:

28kw PV, 12KW grid, 0 battery and 26KW converter, with initial cost: 23,300$, cost of energy: 0.0284 $/KWh and net present cost 23,245$ table. (III) Shows energy rate schedule of Grid.

TABLE III
Energy schedule of Grid

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)
January	1,692	1,593	99	9	($15.96)
February	1,332	1,456	-124	10	($31.74)
March	1,587	1,835	-248	12	($47.37)
April	1,602	1,807	-204	12	($43.45)
May	1,730	1,732	-2	12	($26.16)
June	1,835	1,593	242	12	($4.55)
July	1,909	1,551	359	12	$5.42
August	1,956	1,602	355	12	$4.36
September	1,905	1,741	164	12	($13.01)
October	1,793	1,545	247	12	($3.41)
November	1,701	1,464	237	12	($3.02)
December	1,718	1,432	286	11	$1.44
Annual	20,761	19,351	1,410	12	($177.45)

7. CONCLUSION AND SUMMARY OF RESULTS

The simulation results are summarized in table (IV) showing the system architecture and economic value.

The result shows that the wind hybrid system is not optimal system for buildings located in Cairo, Nasr city. It is found that the hybrid PV/ diesel/battery system is the optimum HRES for the proposed standalone residential building according to the economic cost (cost of energy (COE) and net present cost (NPC)).

The optimum HRES for standalone building consists of 50 kW of PV panels, 17 kW of power converters, 12 kW diesel generator and 80 batteries. After including passive design such (external walls, window to wall ratios and orientations) to compensate for the inefficiencies of this building, the annual electricity consumption decreased. It is found that the optimum HRES for building consists of 50 kW of PV panels, 11 kW of power converters, 6 kW diesel generator and 80 batteries. The cost analysis is performed to select the most optimum RES.

We also found that the grid –tied building is nearly ZEB according to net energy purchased (kwh) from grid. the net-zero energy means the building may use energy from the utility grid (electricity/natural gas) during some times of the day but supplies renewable energy back to the grid during other times, in a balance that equals out over the course of a year.

The over all cost required to retrofit the buildings with the same type and location in Egypt as shown in table(V).

TABLE IV
Cost and energy yield of the optimum solution for grid tied building.

System	Architecture	Net purchased (kwh)	Energy charge ($)	Net present cost($)	Cost of energy($)
Pv- grid (1)	28kw pv 20kw grid 26kw converter	23,439	1,700	47,521	0.0474
Pv-grid (2)	28kw pv 12kw grid 26kw converter	1,410	177.45	23,245	0.0284

TABLE V
Initial cost of systems

System	Before retrofit building	After retrofit building
Standalone building Pv- Diesel-battery Initial cost (L.E)	458,502 L.E	728,420 L.E
Grid-tied building Pv- Grid Initial cost (L.E)	163,000	468,649 L.E

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